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Indirect Detection of Dark Matter WIMPs in a Liquid Argon TPC

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Abstract: We assess the prospects for indirect detection of Weakly Interacting Massive Particles using a large Liquid Argon TPC detector. Signal events will consist of energetic electron (anti)neutrinos coming from the decay of τ leptons and b quarks produced in WIMP annihilation in the core of the Sun. Background contamination from atmospheric neutrinos is expected to be low, thanks to the superb angular resolution and particle identification capabilities provided by the considered experimental set-up. We evaluate the event rates predicted for an annihilating WIMP as a function of its elastic scattering cross section with nucleons. This technique is particularly useful for WIMPs lighter than ~ 100 GeV.

Keywords: Dark Matter, WIMPs, Electron Neutrino, Liquid Argon, TPC.

Contents

1. Introduction

Astrophysical observations, probing gravitational potentials, provide overwhelming evidence for the existence of matter that does not emit or absorb electromagnetic radiation and therefore is known as *dark matter* (for recent reviews see Refs. [1, 2, 3]). Perhaps the most convincing evidence for the existence of dark matter comes from the rotation curves of a large number of spiral galaxies [4, 5]. Additional data, such as that collected by WMAP [6], favours a standard cosmological model in which the Universe is flat and contains about 25% non-baryonic dark matter [7].

Notwithstanding the large set of independent observations favouring its existence, the exact nature of dark matter remains one of the most puzzling mysteries of our time. Particle Physics, through extensions of the Standard Model, can provide potentially viable candidates for dark matter, most of which fall in the class of Weakly Interacting Massive Particles (WIMPs). WIMPs are stable (or very long-lived) particles, with masses ranging from the GeV to the TeV range, which can account for a significant fraction of the dark matter density in the Universe. Among the plethora of WIMP candidates, the lightest neutralino is the most theoretically developed [8, 9, 10, 11]. Another possibility is offered by Universal Extra Dimension models [12], in which the Lightest Kaluza-Klein particle is a plausible dark matter candidate [13].

Parallel to theoretical developments, there also exists an intense and challenging experimental activity devoted to WIMP detection. So far, only a single experiment, DAMA [14], claims to have found evidence for the presence of WIMPs in the Galactic halo. Using a

direct detection method, they have measured an annual modulation, over seven annual cycles (107,731 kg day total exposure), consistent with expectations from a WIMP signature. Other experiments, probing similar regions of the parameter space, have found negative results [15, 16, 17, 18]. Therefore the situation remains highly controversial. Indirect detection methods have produced so far negative results [19, 20].

In this paper we concentrate on indirect detection methods. We assess, in a model-independent way, the capabilities that a massive Liquid Argon (LAr) Time Projection Chamber (TPC) offers for identifying neutrino signatures coming from the products of WIMP annihilations in the core of the Sun. Unlike existing measurements and future searches in large Čerenkov neutrino telescopes [21, 22, 23, 24], where a statistically significant excess of high energy muons is expected to be measured, here we propose to look for an excess of electron-like events over the expected background of cosmic neutrinos. In particular, our signature will be a high energy ν_e and $\bar{\nu}_e$ charged current interactions pointing in the direction of the Sun. We evaluate our sensitivity and present the expected event rates over the mass region of 10 to 100 GeV where this technique is most effective. Note that this includes the mass range favoured by the DAMA experiment [14].

2. Neutrinos from WIMP Annihilation in the Sun

WIMPs that constitute the halo of the Milky Way can occasionally interact with massive objects, such as stars or planets. When they scatter off of such an object, they can potentially lose enough energy that they become gravitationally bound and eventually will settle in the center of the celestial body. In particular, WIMPs can be captured by and accumulate in the core of the Sun.

The capture of heavy particles in the Sun was first calculated in Ref. [25]. Improved formulae for WIMP capture were later given in Ref. [26]. WIMPs can accrete as a result of both spin-dependent and spin-independent (scalar) interactions. The solar WIMP capture rate is given by [26]:

$$C^{\odot} \simeq 3.35\times 10^{20}\mathrm{s}^{-1} \left(\frac{\rho_{\mathrm{local}}}{0.3\ \mathrm{GeV/cm}^3}\right) \left(\frac{270\ \mathrm{km/s}}{\bar{v}_{\mathrm{local}}}\right)^3 \left(\frac{\sigma_{\mathrm{H,SD}}+\sigma_{\mathrm{H,SI}}+0.07\sigma_{\mathrm{He,SI}}}{10^{-6}\mathrm{pb}}\right) \left(\frac{100\ \mathrm{GeV}}{m_{\mathrm{WIMP}}}\right)^2 \tag{2.1}$$

where ρ_{local} is the local dark matter density, $\bar{v}_{\mathrm{local}}$ is the local rms velocity of the halo WIMPs, $\sigma_{\mathrm{H,SD}}$, $\sigma_{\mathrm{H,SI}}$ and $\sigma_{\mathrm{He,SI}}$ are the spin-dependent and spin-independent WIMP-Hydrogen and WIMP-Helium cross sections, respectively, and m_{WIMP} the mass of the WIMP. Throughout this paper, we will refer to the quantity $\sigma_{\mathrm{H,SD}}+\sigma_{\mathrm{H,SI}}+0.07\sigma_{\mathrm{He,SI}}$ simply as the elastic scattering cross section, $\sigma_{\mathrm{elastic}}$.

In this paper, we do not consider the possibility of observing neutrinos from WIMPs accumulated in the Earth. Given the smaller mass of the Earth and the fact that only scalar interactions contribute, the capture rates for our planet are not enough to produce, in our experimental set-up, a statistically significant signal. For a detailed discussion of WIMP capture in the Earth, see Ref. [27].

Accumulated WIMPs will annihilate into ordinary matter (quarks, leptons, gauge and Higgs bosons). In the case of neutralino dark matter, annihilations do not directly produce

neutrinos, as they are Majorana particles [8]. Instead, neutrinos with a spectrum of energies below the mass of the WIMP will be generated in the decays of annihilation products.

Other dark matter candidates may produce neutrinos directly, however. For example, Kaluza-Klein dark matter [28, 29] or sneutrino dark matter [30, 31] can each annihilate directly to neutrino pairs.

As already pointed out, we are only interested in the expected fluxes of electron neutrinos and anti-neutrinos. To compute this, we use the analytic expressions given in Ref. [32]. The differential energy flux is:

$$\frac{d\phi}{dE} = \frac{\Gamma_A}{4\pi R^2} \sum_F B_F \left(\frac{dN}{dE}\right)_F \tag{2.2}$$

where Γ_A is the WIMP annihilation rate in the Sun and R is the distance from the Sun to the Earth. The sum is over annihilation channels, B_F being the fraction of annihilations which go to channel F. $(dN/dE)_F$ is the differential energy spectrum of electron neutrinos at the surface of the Sun per WIMP annihilating through channel F.

The final electron (anti)neutrino flux is obtained using the following set of assumptions:

- We take typical values for the local dark matter density and local rms velocity, namely $\rho_{local} = 0.3$ GeV/cm^3 and $\bar{v}_{local} = 270$ km/s.

- Equilibrium has been reached and therefore the annihilation rate, Γ_A, is equal to the capture rate in the Sun, $C^{\odot}$. This is a reasonable assumption given the range of cross sections we consider here.

- We restrict ourselves to a low mass WIMP scenario, namely $m_{\rm WIMP} \leq 100$ GeV; in this way we minimize neutrino flux depletion due to propagation effects across the Sun.

- Due to the former assumption, phase space considerations avoid WIMP annihilation into top quarks and Higgs bosons. Although in the narrow mass range between 80 and 100 GeV, annihilations to gauge boson pairs (W^+W^-, Z^0Z^0) are possible, we do not explore this channel. We instead focus on WIMP annihilations to the $b\bar{b}$ and $\tau^+\tau^-$ channels. These are generally the dominant channels for a neutralino in this mass range.

  The electron neutrino spectrum from annihilations to $\tau^+\tau^-$ is given (in the relativistic limit) by [32]

$$\left(\frac{dN}{dE}\right)_{\tau^+\tau^-} = \left(\frac{2\Gamma_{\tau\to e\nu\bar{\nu}}}{m_{\rm WIMP}}\right) (1 - 3x^2 + 2x^3)\; e^{-E/E_k}, \tag{2.3}$$

  where $x = E/m_{WIMP}$ and E is the neutrino energy. $\Gamma_{\tau\to e\nu\bar{\nu}} \simeq 0.18$, the branching ratio of taus into an electron plus neutrinos. The factor, e^{-E/E_k}, accounts for the absorption of neutrinos as they propagate through the Sun. $E_k \simeq 130$ and 200 GeV for ν_e and $\bar{\nu_e}$, respectively [33, 34].

The electron neutrino spectrum from annihilations to $b\bar{b}$ is similar [32]

$$\left(\frac{dN}{dE}\right)_{b\bar{b}} = \left(\frac{2\Gamma_{b\to e\nu X}}{z\, m_{\rm WIMP}}\right)(1-3x^2+2x^3)\; e^{-E/E_k} \tag{2.4}$$

Here, $x = E/(z\, m_{\rm WIMP})$ where $z \cong 0.7$ is the fraction of energy retained after hadronization. The inclusive branching ratio for b quarks to electron neutrinos, $\Gamma_{b\to e\nu X}$, is approximately 0.11.

- We consider that tau pairs are produced with a branching fraction $B_{\tau^+\tau^-} = 10\%$ while for b quarks we assume a branching ratio of $B_{b\bar{b}} = 90\%$.

3. The Liquid Argon TPC

The detection device we propose to use for indirect WIMP detection is a Liquid Argon Time Projection Chamber (LAr TPC). This technology was first put forward in 1977 [35]. In a LAr TPC, the ionization charge, released at the passage of charged particles, can be transported over large distances thanks to the presence of a uniform electric field. The signals induced by drift electrons are recorded by a set of successive anode wires planes thus providing three dimensional image reconstruction and calorimetric measurement of ionizing events. Unlike traditional bubble chambers, limited by a short window of sensitivity after expansion, the LAr TPC detector remains fully and continuously sensitive, self-triggerable and without read-out dead time.

The feasibility of the LAr TPC technology has been demonstrated thanks to an extensive R&D programme, developed by the ICARUS collaboration, that culminated in the construction and operation of a 600 ton detector [36]. A surface test of this detector has demonstrated the high level of maturity reached by this technology [37, 38, 39, 40, 41].

Future applications of this detector technology have been proposed to study neutrino properties within the context of neutrino factories [42, 43] or to study neutrinos from supernovae [44]. An interesting long-term application is the possibility to build a giant LAr TPC detector with a mass of 100 ktons. The technical aspects and physics prospects of such detector have been extensively discussed elsewhere [45, 46]. In the present paper we evaluate for the first time the capabilities that such a detector will have in the search for dark matter WIMPs.

We have focused our interest on ν_e, $\bar{\nu}_e$ charged current events, since a LAr TPC offers very good electron identification capabilities. In addition, all final state particles can be measured and identified (see figures 1 and 2 where a full simulation of a ν_e charged current interaction is shown). Thanks to the high granularity and superb imaging capabilities, we expect to have a very accurate measurement of both energy and incoming direction. Therefore our signal will correspond to a neutrino interaction that points in the direction of the Sun and contains an energetic primary electron. Possible background sources are extensively discussed in the next section.

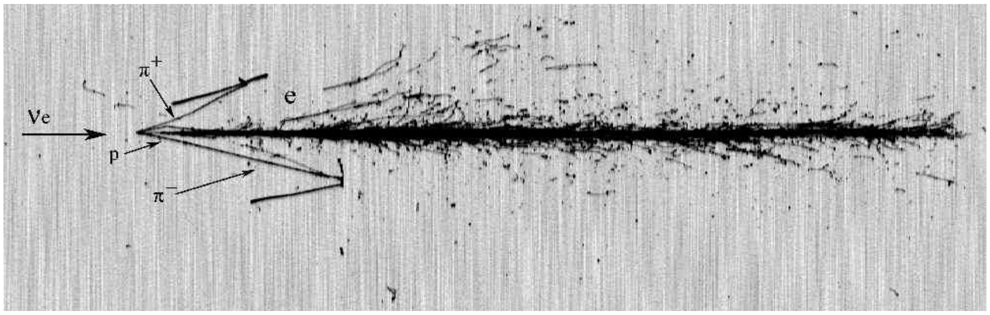

Figure 1: Simulated ν_e interaction in a Liquid Argon detector (longitudinal view). The electron neutrino ($E_\nu = 26.3$ GeV) travels from left to right and suffers a charge current interaction with the atoms of the medium, resulting in a highly energetic electron (23 GeV), two pions ($E_{kin} = 0.7$ and 1.4 GeV) and a proton ($E_{kin} = 1.6$ GeV). This last particle is not visible in this projection. The neutrino direction is computed combining the information coming from the electromagnetic shower and the hadronic jet.

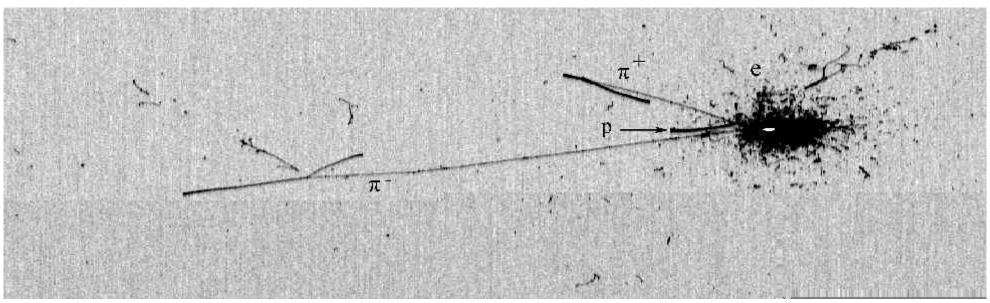

Figure 2: Rotated view of the same ν_e interaction shown in figure 1. In this projection the four particles coming out from the main interaction vertex are clearly visible: two pions, one proton and the electron (that appears as a big black spot).

4. Sources of ν_e Background

We have identified several sources that could, a priori, significantly contribute to the expected background rate. The most obvious is atmospheric neutrinos, where we expect contributions from both $\nu_e/\bar{\nu}_e$ charged currents and $\nu/\bar{\nu}$ neutral currents (where a π^0 is misidentified as an electron). In the energy range we study here (~10 to 100 GeV) solar neutrinos do not significantly contribute to the background. We have also considered the flux of neutrinos originating from cosmic ray interactions with the interstellar medium in the galaxy. As shown in Ref. [47], for the range of energies considered in this study, this flux is negligible compared to the atmospheric flux. The diffuse flux of ν_e from active galactic nuclei is also small.

Fluxes of ν_τ are also a concern given that τ leptons, produced in charged current interactions, can subsequently decay into electrons. According to Ref. [48], the expected flux of ν_τ from sources like atmospheric neutrino oscillations, the galactic plane and galaxy clusters are small and will not give a significant contribution in our energy range.

Therefore, the most important source of background is by far due to atmospheric neu-

trinos. The evaluation of this flux ϕ_ν has been performed using the calculations published in Ref. [49]. In this paper the authors present a detailed 3-dimensional calculation of the atmospheric neutrino flux based on the `FLUKA` Monte Carlo model [50]. The final `FLUKA` tables for three experimental sites (Kamiokande, Gran Sasso and Soudan) are also accessible in Ref. [51].

Figure 3 shows the differential atmospheric electron neutrino flux as a function of the neutrino zenith angle and the neutrino energy expected at the latitude of Gran Sasso [51]. Similar distributions are built and used for $\bar{\nu}_e$, ν_μ and $\bar{\nu}_\mu$. Only neutrinos in the energy range $1 - 100$ GeV are shown.

Without loss of generality, the spectra at Gran Sasso has been taken as reference for all calculations presented in this work. The conclusions of the paper remain valid for other underground laboratories such as Kamiokande or Soudan since the neutrino fluxes at these locations are expected to be similar (at high energies, differences are less than a percent [51]).

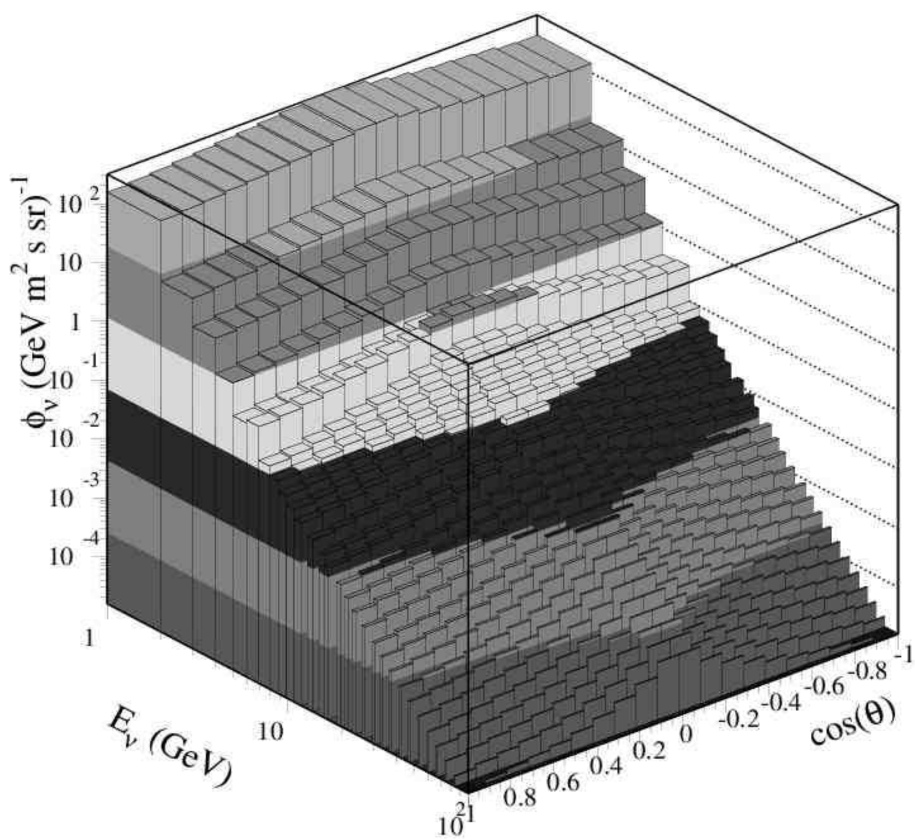

Figure 3: Differential atmospheric electron neutrino flux as a function of the neutrino energy and zenith angle. The data, taken from Refs. [49, 51], correspond to the Gran Sasso latitude and is taken as our reference to compute the expected background rate.

5. Data Analysis

The number of expected background events contributing from each neutrino species (N_{ν_i}) is determined from simple integration of the associated atmospheric differential neutrino flux (ϕ_{ν_i}) taking into account the involved cross sections (σ_{ν_i}), the detector mass (M_d) and the data taking period:

$$N_{\nu_i} = \int \phi_{\nu_i}(E,\theta) \cdot \sigma_{\nu_i}(E) \cdot M_d \;\; dE \, d\Omega \, dt, \tag{5.1}$$

where the integration is done above a minimum energy threshold, E_ν^{min}, and inside a limited solid angle on the sky, $\Delta\Omega$, in order to reduce the background contribution. In the following we assume a detector mass of 100 ktons of LAr and 10 years of data taking.

We have taken into account not only Charged Current (CC) events for ν_e and $\bar{\nu}_e$ interactions but also Neutral Current (NC) events for both electron and muon species. Neutral current events contribute to the background mainly through (1) electrons from Dalitz decays and (2) misidentified pions. In this work we have assumed a conservative 90% efficiency on the rejection of NC events, even though Monte Carlo studies on LAr detectors show much better capabilities (>99%). ν_μ and $\bar{\nu}_\mu$ CC interactions are excluded from the calculation since the presence of a muon in the final state would immediately veto the event as a possible ν_e (the muon–electron misidentification probability in a LAr detector is almost zero).

In general, when looking at neutrinos coming from astrophysical point–like sources, the atmospheric neutrino background can be reduced to a very low level by selecting small angular regions of the sky. This applies to our particular problem where we are interested in neutrinos coming only from the Sun. Therefore the region of interest is of the order of the angular size of the Sun and, in principle, the neutrino background coming from this narrow sky window will be small.

At this stage we have to estimate $\Delta\Omega$, the apparent size of the Sun "seen" by the detector. Its value will be driven by our capabilities to determine the incoming neutrino direction, i.e. the detector angular resolution. This calculation has been carried out through a detailed and realistic simulation of neutrino interactions inside a LAr detector. Neutrinos of different species in a wide energy range (< 100 GeV) and the final state particles, produced after the ν interaction, were tracked using the `FLUKA` package. As an example, figures 1 and 2 show a picture of one of these simulated events where a 26.3 GeV electron neutrino (flying from left to right) undergoes a CC interaction giving rise to several secondary particles: $\nu_e \, n \rightarrow e^- \, p \, \pi^+ \, \pi^- \; (2n \, 3\gamma)$. The three charged hadrons appear as dark thin lines over light grey background, the electron develops as an electromagnetic shower and the neutral particles are invisible. The reconstruction of the ν direction is done using the information coming from all particles produced in the final state.

The result of the simulation is shown in figure 4, where the difference between the simulated and reconstructed neutrino directions, $\Delta\theta$, is plotted as a function of the incoming neutrino energy (solid curve). Note that for the considered energy range, O(10 GeV), the smearing introduced by the Fermi motion of the initial state nucleon and by re-interaction

of hadrons inside the nucleus are negligible and the improvement on the neutrino direction measurement achieved by combining the electron and the hadronic jet informations is significant. Due to the excellent reconstruction capabilities offered by the LAr technique, the angular resolution remains below 2° for the highest energies up to about 15 GeV, increasing by a factor of 4 at lower energies (~ 5 GeV).

In case of an ideal detector with perfect angular resolution, the sky integration window would be limited to the size of the Sun ($\sim 6.7 \cdot 10^{-5}$ sr). In our more realistic scenario $\Delta\Omega$ has been estimated by smearing this number with the detector resolution. The dashed line in figure 4 shows the resulting half size of the Sun (radius) after the smearing (see right axis). For comparison, the real Sun radius seen from the Earth ($\sim 0.256°$) is also plotted.

Concerning the signal, the number of expected events is computed in a model independent way as described in section 2 by integrating equation 2.2 between E_ν^{min} and the WIMP mass. Contributions from electron neutrino oscillations in the range of considered neutrino energies (above 10 GeV) are negligible. Therefore, no loss or gain on signal events from oscillated neutrinos is taken into account.

The final estimation for a 50 GeV WIMP mass is presented in figure 5 where we show the number of expected signal (squares) and background (dots) events as a function of the cut on the minimum neutrino energy. The numbers are normalized to a 100 kton LAr detector and 10 years of data taking and for a WIMP elastic scattering cross section in the Sun of 10^{-4} pb (the result can be easily rescaled to other exposures or cross sections). As expected, the background rate quickly decreases when increasing the neutrino energy cut because of (1) the nature of the atmospheric neutrino flux and (2) the better detector angular resolution. From this figure we conclude that the search can be safely considered as "background free" for values of $E_\nu^{\rm min}$ above ~ 10 GeV (contamination ~ 0.2 events).

Figure 6 gives the evolution of the signal events as a function of the WIMP elastic scattering cross section, for neutrinos of energy above 10 GeV and three values of the WIMP mass. The background (horizontal line) is below the signal for values of $\sigma_{\rm elastic}$ above $\sim 5 \cdot 10^{-6}$ pb.

6. Prospects for Discovery

In section 5 we have evaluated the average number of signal and background events (called hereafter μ_S and μ_B, respectively) expected in the detector for a certain exposure, $\mathcal{E} =$ Mass $\times$ time $=$ 100 ktons $\times$ 10 years. At this point we would like to know whether a numbers of expected events from a particular dark matter model will allow the experiment to claim a discovery at a certain significance level. This problem is fully discussed in Ref. [52], where a general and well defined *criterion of discovery* is proposed for statistical studies of this nature:

- Usually a 5σ criterion (called "`method A`" hereafter) is used, so that in order to consider that a discovery will take place, the signal must be above a 5σ fluctuation of the background: $\mu_S > 5\sqrt{\mu_B}$.

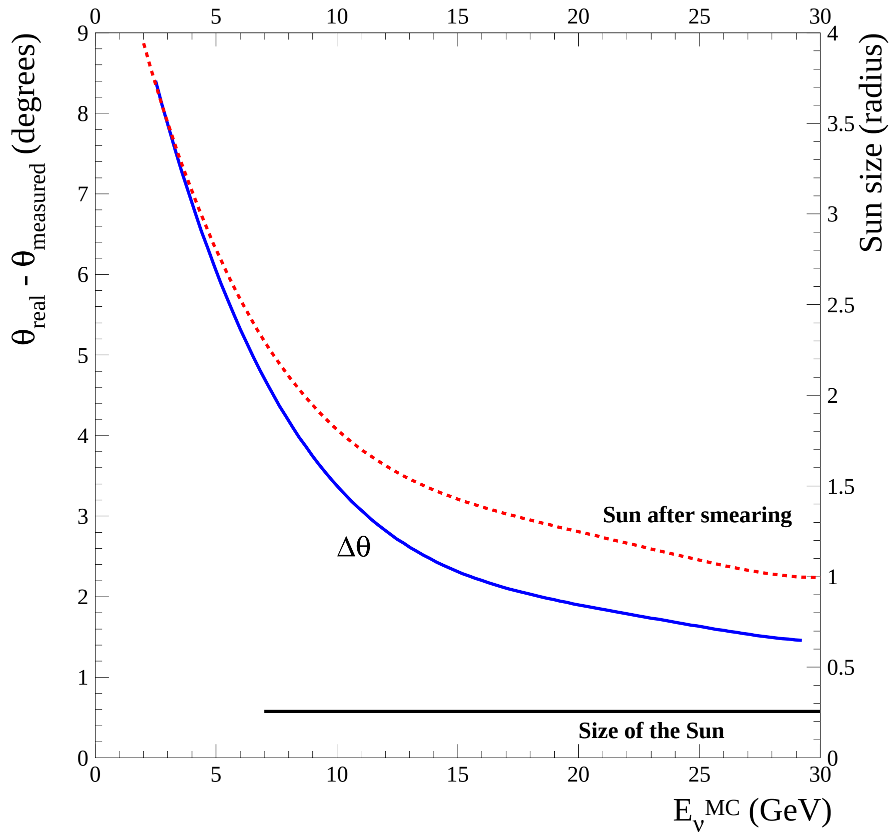

Figure 4: Detector angular resolution ($\Delta\theta$) as function of the incident neutrino energy obtained from a Monte Carlo simulation in a LAr detector (solid line and left axis). The figure also shows the size of the Sun (radius) for an ideal detector (horizontal solid line) and the resulting apparent size after detector smearing (dashed line, read on the right axis).

This commonly used rule frequently gives misleading (if not clearly wrong) results. Only when μ_S and μ_B are large enough to describe with Gaussian distributions can this rule be applied. This is clearly not the case in our study.

- Instead, we have followed the method proposed in Ref. [52] ("`method B`" hereafter), where the discovery criterion is given by two numbers, namely: ϵ, the significance required to consider an excess of events a discovery, and δ, the probability that the experiment will obtain such an excess. For instance, when $\delta = 0.5$ and $\epsilon = 5.733 \times 10^{-7}$, we can state that at least 50% of the time, the experiment will observe a number of events which is 5σ or more above the background.

The results based on "`method B`" ($\delta = 0.5$ and $\epsilon = 5.733 \times 10^{-7}$) are presented in figure 7. The plot shows the minimum number of years required to observe a WIMP positive discovery signal as function of the WIMP elastic scattering cross section. The

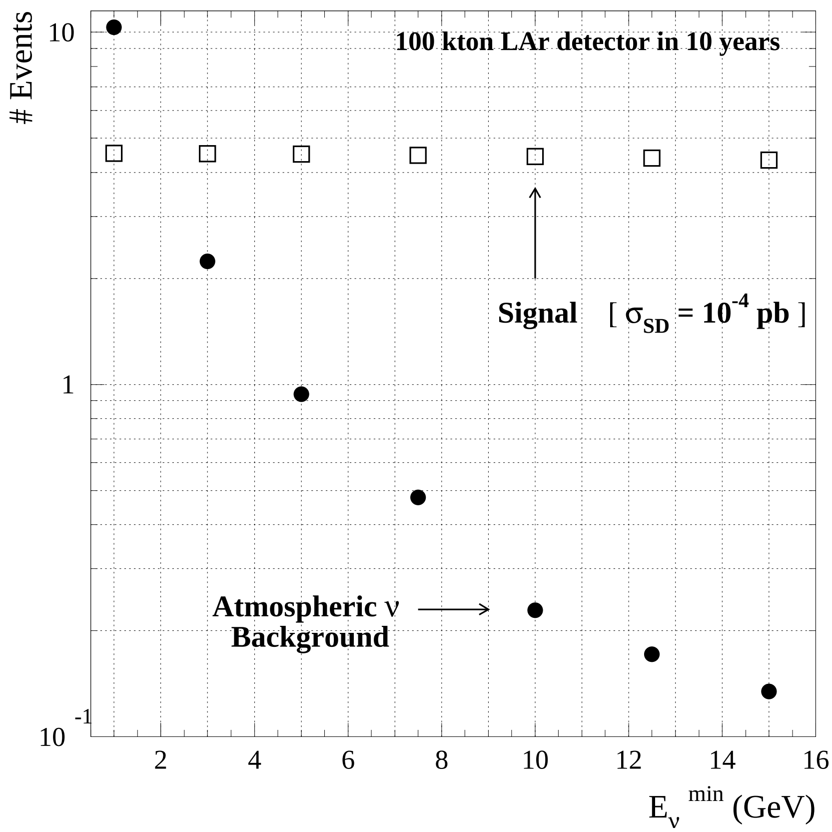

Figure 5: Expected number of signal and background events in a 100 kton LAr detector after 10 years of data taking as function of the cut on the minimum neutrino energy. Signal events correspond to a 50 GeV WIMP mass and are normalized to a elastic scattering production cross section in the Sun of 10^{-4} pb. The number of atmospheric neutrino events includes contributions from muon and electron (anti)neutrinos, and takes into account the detector angular resolution.

numbers are given for three values of the WIMP mass and only neutrinos above 10 GeV are considered.

From this result we conclude that, in 10 years of data taking, a 100 kton LAr detector would be able to claim a clear discovery signal according to "`method B`", provided σ_{elastic} is above $\sim 10^{-4}$ pb for WIMP masses greater than 20 GeV. On the other hand, only one year of data taking would be enough to observe a discovery signal provided σ_{elastic} is above 5×10^{-4} pb and m_{WIMP} $\sim$20 GeV.

Finally, we have studied the sensitivity of the results with the cut on the minimum neutrino energy. We remind the reader that the value of E_ν^{min} sets the energy above which all events are integrated. By lowering the cut we would accept too many atmospheric background events and by increasing it both, μ_S and μ_B decrease, but at different rates (see figure 5). The quantitative result in terms of discovery prospects are shown in figure 8 for two values of E_ν^{min} and a reference WIMP mass of 50 GeV.

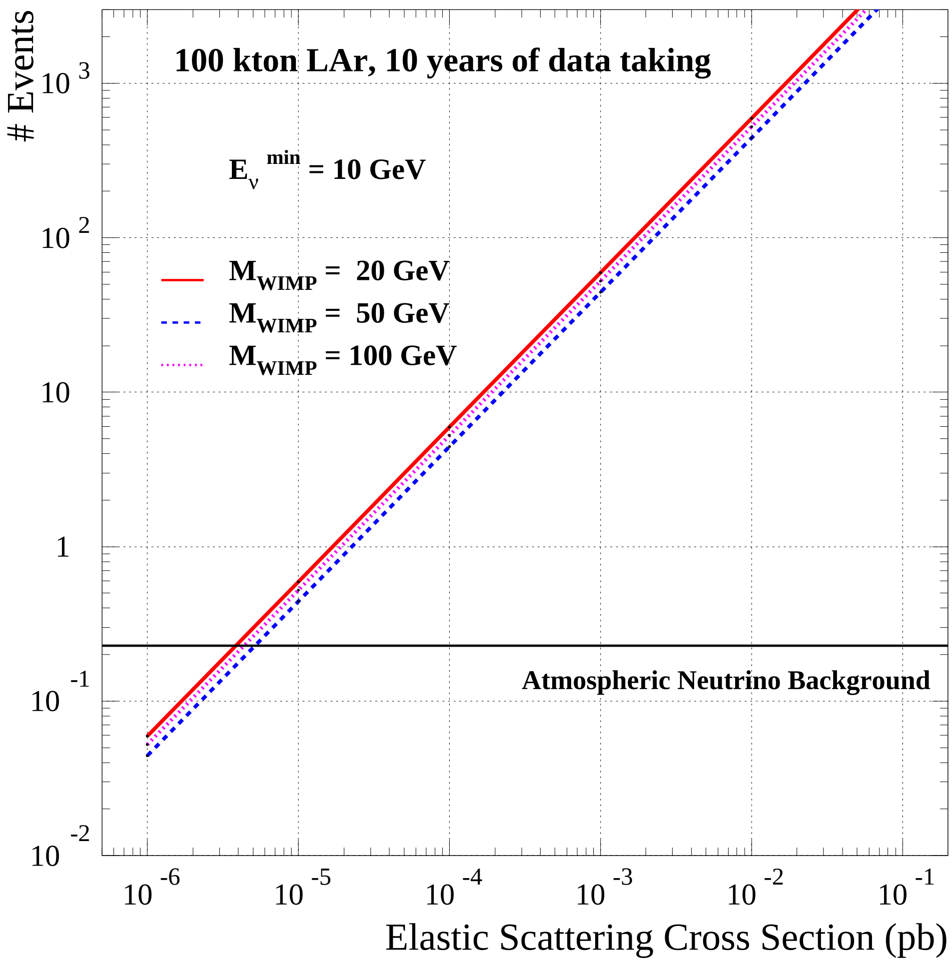

Figure 6: Expected number of signal and background events as a function of the WIMP elastic scattering production cross section in the Sun. The three lines correspond to three values of the WIMP mass and a cut on the minimum neutrino energy of 10 GeV.

7. Comparison to Other Indirect Detection Techniques

Using neutrino detectors to search for evidence of dark matter has been studied in the context of several experiments. Currently, high energy neutrino telescopes that use large volumes of a natural Cerenkov medium (such as ice or water) show the greatest promise for dark matter detection. The AMANDA experiment, located at the South Pole, has been taking data for several years. Its successor, IceCube is currently under construction at the same site. When completed, IceCube, will constitute the largest neutrino detector to date, with a full cubic kilometer of instrumented volume. The ANTARES experiment is currently under construction in the Mediterranean. Although its effective volume will be considerably smaller than IceCube's, ANTARES has been designed to be sensitive to neutrinos of lower energy, and therefore may be competitive with IceCube for detecting

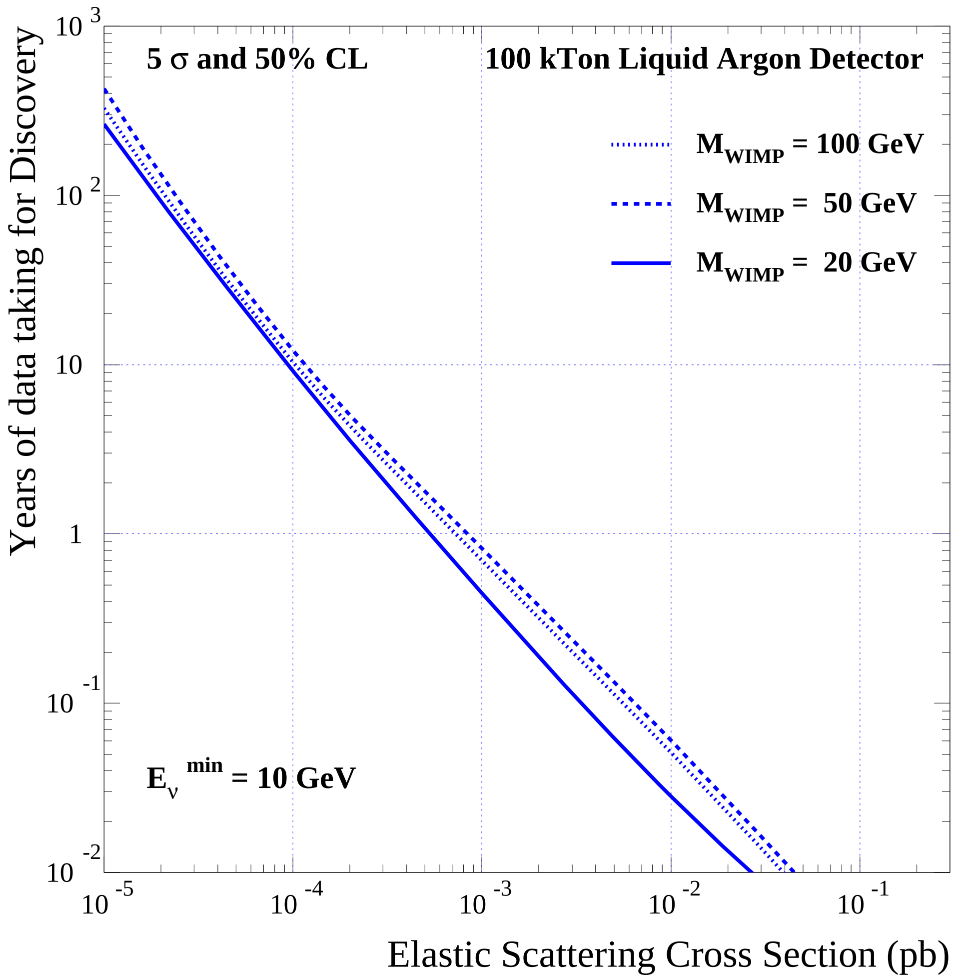

Figure 7: Discovery potential: Minimum number of years required to claim a discovery WIMP signal from the Sun in a 100 kton LAr detector as function of σ_{elastic} for three values of the WIMP mass. See text for details on the applied statistical criteria.

dark matter.

At the energies we are considering here (well below a few TeV), neutrino telescopes observe neutrinos through energetic muons produced in charged current interactions. The direction of these neutrinos can only be reconstructed to $\sim 1.2^\circ/\sqrt{E_\mu(\text{TeV})}$, the angle at which the muon and neutrino are aligned. The angular cuts which can be imposed when searching for a signal from the Sun are thus considerably weaker than for the liquid Argon technique described in this article. Overcoming the atmospheric neutrino background is an essential requirement if a liquid Argon TPC detector is to succeed.

Experiments such as AMANDA, ANTARES and IceCube are (or will be) considerably larger than the 100 kton liquid Argon TPC detector we use here. The target mass of IceCube is approximately 10^4 times greater, for example. For very massive WIMPs (heavier

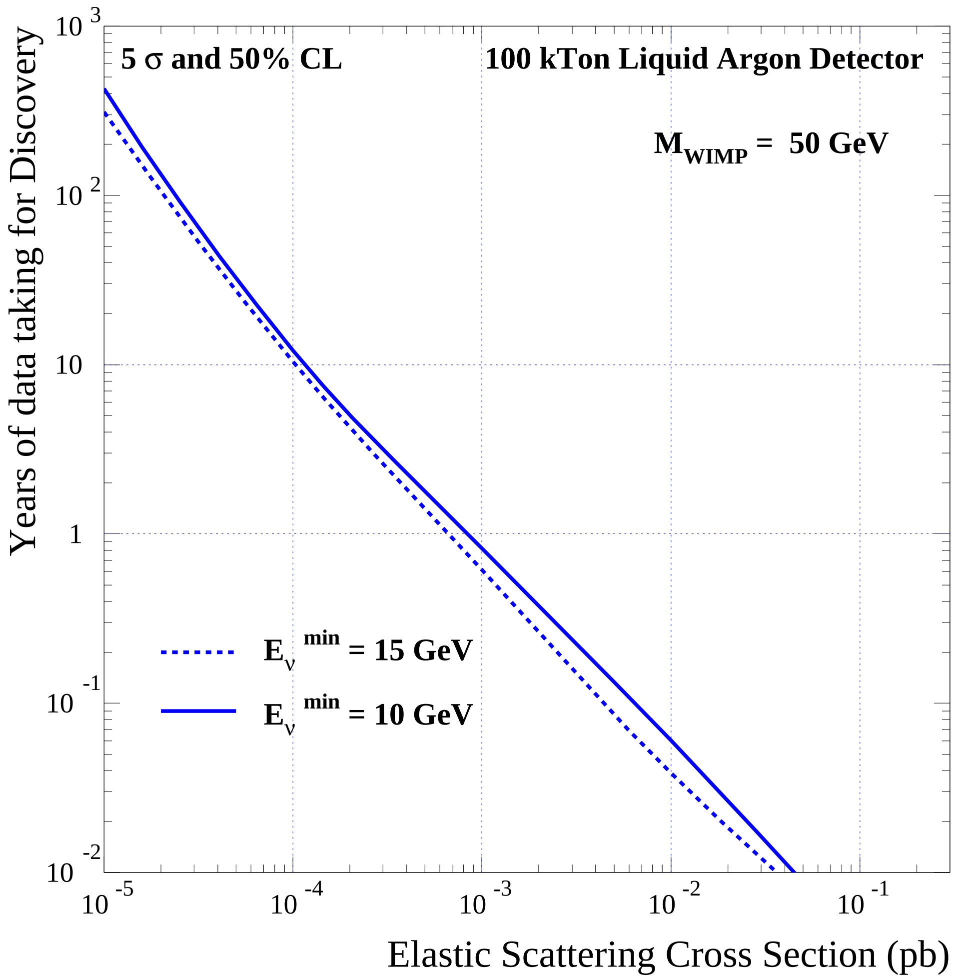

Figure 8: Detector discovery potential for two values of the minimum neutrino energy cut and a 50 GeV WIMP mass. See text for details on the applied statistical criteria.

than 100-200 GeV), high-energy neutrino telescopes provide a considerably more sensitive probe of dark matter annihilations than the technique described here. For lighter WIMPs, however, this may not be the case.

Considering a 50 GeV WIMP, for example, we expect neutrinos to be generated with energies on the order of 15-20 GeV and lower (assuming the annihilation modes discussed in section 2). Although such neutrinos are well within the energy range that a liquid Argon detector could be sensitive to, they would generate muons with energies of 8-10 GeV, which are below the threshold for planned high-energy neutrino telescopes. Neutrinos from WIMPs lighter than ~ 100 GeV are likely to be missed by high-energy experiments, but are ideal for a liquid Argon TPC detector.

For discussions of the prospects for the detection of dark matter with high-energy neutrino telescopes, see Refs. [53, 54, 55, 56].

8. Conclusions

In this paper we have studied the ability of a giant Liquid Argon Time Projection Chamber (TPC) to detect dark matter indirectly via observation of neutrinos produced in WIMP annihilation in the core of the Sun. We have adopted an approach which differs from previous studies, where an excess of upward-going muons would signal the presence of WIMPs in the core of the Sun or the Earth. Our method takes advantage of the excellent angular reconstruction and superb electron identification capabilities Liquid Argon offers to look for an excess of energetic electron (anti)neutrinos pointing in the direction of the Sun. The expected signal and background event rates have been evaluated, in a model independent way, as a function of the WIMP's elastic scatter cross section for a range of masses up to 100 GeV.

We have also presented a prospective study that quantifies the detector discovery potential, i.e. the number of years needed to claim a WIMP signal has been discovered. With the assumed set-up and thanks to the low background environment offered by the LAr TPC, a clear WIMP signal would be detected provided the elastic scattering cross section in the Sun is above $\sim 10^{-4}$ pb.

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